THIN FILM MODULES CHARACTERIZATION UNDER STANDARD TEST CONDITIONS

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ABSTRACT: Photovoltaic modules based on the relatively new thin film technology are gaining importance in the photovoltaic market. Some of these modules are made of silicon, consisting of layers of amorphous silicon or microcrystalline silicon. Other thin film PV modules are made of CIS, Cadmium Telluride (CdTe) or less frequently organic compounds. The materials used in thin film technologies pose problems in terms of measuring how much power is generated under standard test conditions (STC). This is due to the fact that the modules´ power rates could vary depending both on the amount of time they have been exposed to the sun and on their history of sunlight exposure. So it is necessary to know the previous periods of sunlight exposure in order to know the current state of the module.
It is necessary to determine an easily accomplishable testing method that ensures the repeatability of the measurements of the power generated. This is essential because in order to have a reliable sample of the PV module population of a large PV plant, a huge number of modules must be measured.
This paper shows different tests performed on different commercial thin film PV modules in order to find the best way to obtain measurements. A correlation was tested between sun exposure and power measured. A method for obtaining indoor measurements of these technologies that takes periods of sunlight exposure into account is proposed. Additionally, temperature and irradiance coefficients were also determined for different technologies in order to obtain accurate measurements.

Keywords: PV Module, Light-Soaking, Power Conditioning, Thin Film, CdTe

1. INTRODUCTION

The Electrotechnical section of the Rural Engineering Department at the Polytechnic University of Madrid forms the core of a research group named “Energy and Agriculture”. Some members of the group are involved in research related to photovoltaic modules used in agricultural systems such as greenhouses. The group collaborates with CIEMAT in their research.
During the past years, an important number of PV module installers have asked CIEMAT PVLabDER about a reliable method of indoor and outdoor testing thin film PV modules in order to verify their properties under standard test conditions (STC). CIEMAT PVLabDER has significant experience in measuring “traditional” silicon PV modules and has agreed to develop this type of testing method.

This paper presents a method to determine the actual power generated by different thin film technologies in order to determine the relationship between indoor and outdoor tests. In these kinds of PV modules, the effect of light soaking must be taken into account because some thin film technologies present memory effects after sunlight exposure. In order to create a reliable indoor test, it is necessary to take into account the PV module’s history of sunlight exposure as well as the light spectrum and the sunlight activation effect.

2. OBJECT OF ANALISYS

Different technologies have been analyzed all of them based on thin film technology. The main object is to find the best method to obtain the I-V parameters of a PV module at STC in the easiest way. These technologies sometimes need to be preconditioned and also different corrections must be applied.

2.1. Influence of light spectrum in different technologies.

The IEC 60904-1[1] standard establish the general method for measurement of photovoltaic current-voltage characteristics and besides this, the IEC 60904-3 [2] standard establish the spectral distribution of the light that should be used when a measurement of the electrical characteristics of a PV module is made. It is known as 1.5AM and the actual spectral distribution of the sunlight should be measured in any electrical test of a module under sunlight exposition.

Sometimes it is not possible and it is very difficult to assure 1.5AM spectral distribution both indoors and outdoors. Nevertheless using sunlight the spectral distribution is not as stable as indoors therefore into a solar simulator the repeatability of the measurement is easier to achieve. In this case the problem is reduced to take periodically a measurement of the light spectrum inside the simulator.

Each technology has a different spectral response (Figure 1). As the measurement of the electrical characteristics must be translated to STC, a spectral correction must be applied. It usually means that the obtained current has to be multiplied by a spectral factor that depends on the spectral response of the technology under analysis and the spectral distribution of the light.

It is also possible to use a calibrated cell of the same technology and type of the PV module under analysis for the control of the light of the simulator. In this case the problem is that changing this cell often could imply a risk in the repeatability of the measurements of the solar simulator. For this reason a spectral correction for each technology is preferred.

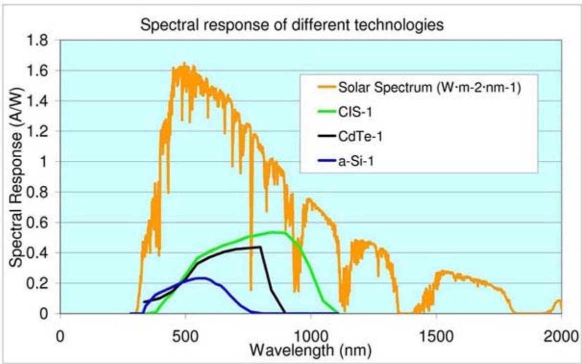

Figure 1.- Typical spectral response of different thin film technologies and AM1.5 spectral distribution.

2.2. Initial degradation in a-Si

PV modules based on a-Si technology have a good rate of cost per watt. Nevertheless the initial stabilization of the electrical characteristics should be taken into account before the measurement of maximum power at STC. This initial power loss typically can be around 16% but higher power loss usually may appear in the first months of use. In this study two a-Si modules were exposed to sunlight in order to achieve its stabilized state.

The results for one of the modules can be observed in Figure 2. Measurements of the electrical characteristic were taken periodically in order to determine if the stabilized power was achieved. Manufacturers of a-Si PV modules trend to assure a maximum power loss by year that is referred to the stabilized power. Last a-Si manufacturers assure a maximum power after 10 and 25 years (90% after 10 years and 80% after 25 years of operation) that is not very different to those assured by c-Si manufacturers.

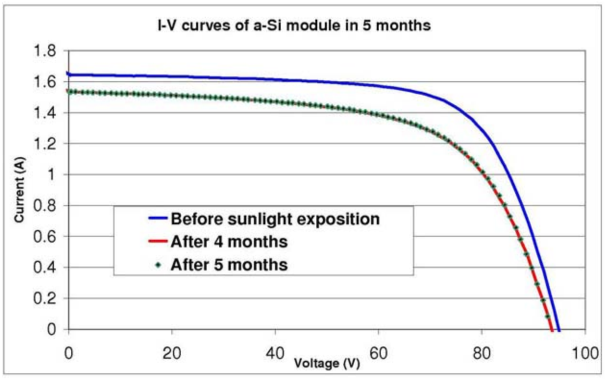

Figure 2.- Initial power stabilization in an a-Si PV module tested in CIEMAT.

2.3. Light activation in CIS

PV modules based on CIS or CIGS technology present an effect of light activation after light soaking that allows recovering the efficiency lost during a period in dark conditions known as dark aging [3] . That is the reason why previously to a measurement of a PV module of this technology it must be exposed to sunlight for at least one hour at 1000W/m^2.

Besides the effect of light activation, an initial lost of power or power stabilization that can not be recovered with light soaking is present. To obtain a correct measurement of a CIS PV module this stabilization should be achieved. This can be performed storing the module in dark conditions for ten days and re-activating it by means of light soaking after this initial period. Further periods of dark will decrease the efficiency of the PV module but in this case the effect will be reversible by means of light soaking cycles

2.4. Light activation in CdTe

Different studies have showed the light activation effect that occurs in Cadmium Telluride PV modules [4]. This effect consist of an increase in the maximum power that the PV module can supply after it has been exposed to sunlight for some hours. The difference in power before and after exposure depends on the thickness of the cell [5] and affects to Voc. The effect is similar to that described for CIS PV modules but in this case the power decrease more rapidly when the module is situated indoors. This can pose a problem when indoor measurements are going to be obtained.

3. ANALYSIS PROCEDURE.

3.1. Indoor measurements

In order to obtain a repeatable measurement of the I-V characteristic curve a class AAA pulsed solar simulator was used. I-V curve measurement was performed according to IEC 60904-1[1][2] , what permits to obtain main parameters, Isc, Voc, Im, Vm Pm and FF at Standard Test Conditions (STC):

- Irradiance: 1000 W/m²
- Cell temperature: 25°C
- Spectral distribution: AM1.5G (according to IEC 60904-3)
- Normal incidence

Measurements were performed indoors, with a flash pulsed class AAA IEC 60904-9[6] solar simulator (10 ms pulse). All measurements were done at temperature and irradiance conditions very closed to STC (1000 ± 5 W/ m^2 and 25 ± 2° C). Short circuit current and open circuit voltage were extrapolated to 1000 W/m² and 25°C using α and β coefficients respectively. The influence of these corrections is minor, due to the small difference between measured and standard conditions.

In some cases a preconditioning should be applied in order to fit the conditions that manufacturers indicate for their PV modules. In some cases it must be taken into account that measurements should be done in a very short time after the preconditioning as is the case for CdTe PV modules. On the contrary the module could lose the activated state and the measurements would not be valid.

3.2. Preconditioning in different technologies

<u>a-Si.- stabilization</u>

As it was mentioned before this technology suffers an initial power descent known as power stabilization that could reach 20% in a few months of sunlight exposition. This mean that prior to give a reliable data of the electrical characteristics of an a-Si PV module it must be exposed to sunlight and a measurement must be taken periodically. When the power does not descent more than 1% in a month it can be said that the stabilized power has been achieved and this is the moment when the actual power of the module can be measured.

Once the stabilization is achieved a measurement of the power can be obtained indoors in a solar simulator which light spectrum is well known and stable applying the spectral correction over the measurements.

CIS.- Activation

Before measurements of CIS or CIGS PV modules are taken, modules must be exposed to sunlight for the modules accumulate at least 20kW/ m^2 of radiation. Also the power stabilization should be achieved storing the modules for ten days in dark conditions and re-activating them by means of light soaking.

When CIS modules are under sunlight exposition for the first time for several days, a power stabilization effect could appear and their initial power decreases of around 3%. In Table 1 it can be observed the mentioned initial power decrease that could not be recovered.

Nº	Pm(W)	Voc(V)	Isc(A)	Vm(V)	Im(A)	FF(%)
1	77.26	46.21	2.41	36.68	2.11	69.4
1b	73.61	45.86	2.34	37.08	1.99	68.5
2	75.53	45.93	2.40	36.89	2.05	68.6
2b	73.79	45.92	2.36	36.65	2.01	68.2
3	73.58	44.14	2.49	35.16	2.09	67.1
3b	71.57	44.32	2.43	34.60	2.07	66.5
4	75.10	44.25	2.49	35.27	2.13	68.2
4b	71.98	44.20	2.42	34.80	2.07	67.2

Table 1.- Measurements before and after the initial power stabilization of CIS modules. Test named with letter "b" were obtained after 8 days of sunlight exposition

CdTe.- Activation

Before a measurement over a CdTe PV module is going to be committed both the stabilized power and the light soaking effects should be achieved.

In order to determine the power that a module could lose during the first days of operation a sample module should be exposed to sunlight in order to accumulate from 20kWh/ m^2 to 40kWh/ m^2 according to EN 50380 [7] and measurements must be taken before and after exposure in the same conditions (after been stored in dark conditions for a week).

For each PV module the light soaking effect must be taken into account and it should be exposed to direct sunlight for at least 4 hours before a measurement is taken outdoors or indoors.

3.3. Temperature coefficients for CdTe.

In a-Si and CIS technologies temperature coefficients are better known than in CdTe. For this reason these coefficients were obtained at CIEMAT for CdTe.

The method to obtain these coefficients must take into account that only temperature should vary during the test. Besides, in this technology the activation effect due to sunlight must be considered. For this reason it is not allowed to shadow the module to reduce the temperature but a mechanism based on watering was used. The modules were refrigerated using water on its front side until it reached a temperature below 25ºC. Later on, measurements of irradiance, temperature and the variable under test (Voc or Isc), were obtained every 10s for 15m. During this time the temperature increased from about 25ºC to 50ºC. A day with no clouds and the central hours of the day were chosen. The test was performed over four different CdTe. In Figure 3 the results of the test over one of the CdTe PV modules are shown. The mean value for the temperature coefficient of Voc (known as beta coefficient) was 0.29%/ºC.

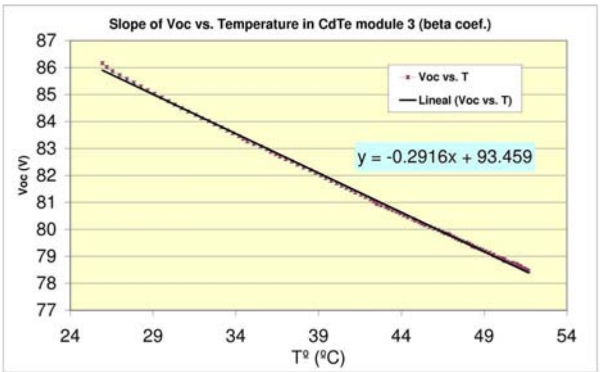

Figure 3.- Temperature coefficient for Voc of a CdTe PV module.

The temperature coefficient for Isc must take into account the stability of the irradiance during the test. As the irradiance is registered the Isc is adjusted to what would be obtained at 1000W/ m^2 in order to avoid its influence.

The mean value for the temperature coefficient of Isc (known as alfa coefficient) was 0.015%/ºC. In this case it is more difficult to obtain a precise coefficient due to the low variation of the Isc and the gradient of the temperature from the front side of de PV module to the back side (Figure 4).

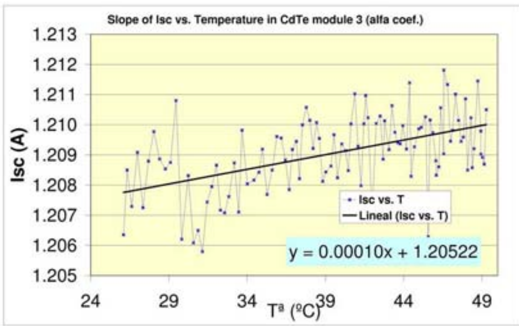

Figure 4.- Temperature coefficient for Isc of a CdTe PV module.

3.4. Outdoors vs. Indoors measurements for CdTe.

Indoors measurements were taken after a period of sunlight activation exposing the PV module to direct incidence of sunlight in a sunny day for at least four hours including the central hours of the day. The temperature was reduced before the indoor test using water refrigeration, watering the PV module just before the measurements.

In order to determine the accuracy of indoors measurements a set of outdoor measurements were committed. Four modules were tested under conditions very close to STC. The method to assure a stable temperature close to 25ºC consisted of several water diffusers situated against the back side of the PV module as can be seen in Figure 5. The water pressure was regulated until the temperature was stable around 25ºC as the PV module was exposed to direct sunlight with normal incidence.

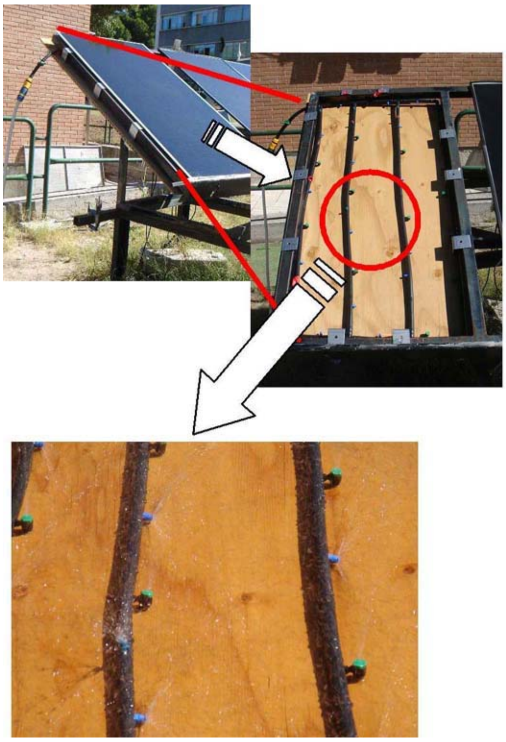

Figure 5.- Configuration of the system to obtain measurements outdoor at 25ºC.

Once the PV module had a stabilized temperature around 25ºC and the irradiance was close to 1000W/ m^2 four measurements were taken in order to determine if all of them were well obtained. Despite of conditions were very close to STC, these measurements were extrapolated to STC using the irradiance and temperature coefficients. Finally outdoors measurements were compared to measurements taken indoors. It must be noticed that both measurements (outdoors and indoors) were obtained after a period of at least five hours of sunlight exposition of the modules in order to achieve the light activation state of them.

In Figure 6 it can be observed that when the explained coefficients are applied measurements taken outdoors and indoors are quite similar and differences around 1% in Pm indicate this situation.

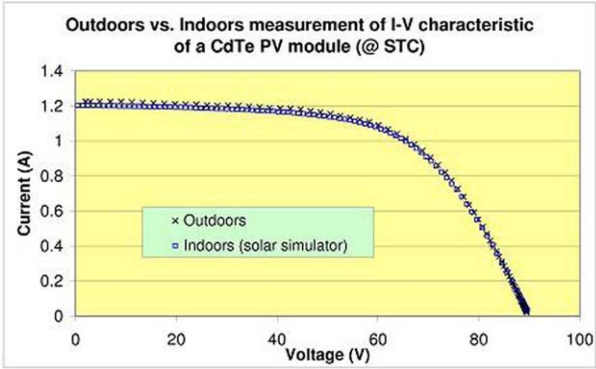

Figure 6.- Comparison of outdoor and indoor measurement of I-V characteristic of a CdTe PV module at STC after sunlight activation.

3.5. Test of time for de-activation in CdTe.

This test was performed indoors due to the fact that a comparative analysis was necessary instead an exact measurement of the actual power in order to determine the time that could pass after the sunlight activation until a power measurement is taken. Nevertheless prior to the measurements indoors every module under analysis was preconditioned by being exposed to sunlight in a sunny day for at least four hours and its temperature was reduced using the same method explained before for outdoors measurements (watering).

Eight test were performed successfully over six CdTe PV modules. The performance of each PV module was not always the same but in all of them a Pm and Voc loss was detected as the time passed. In Figure 7 it can be seen how PV module power decrease as time passes.

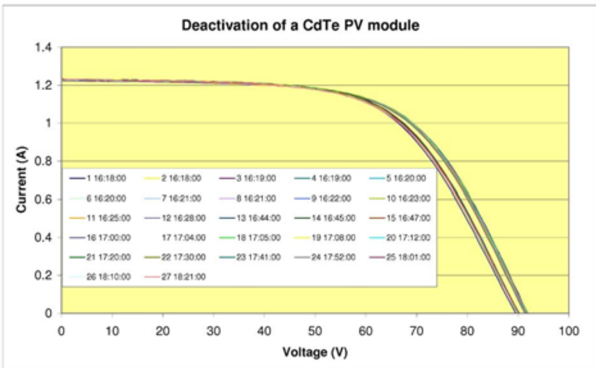

Figure 7.- Deactivation of a CdTe PV module along 2 hours

Not only the Pm and de Voc was affected by the deactivation but also FF [8]. In Figure 8 can be observed how these three parameters descended during the deactivation of the PV module.

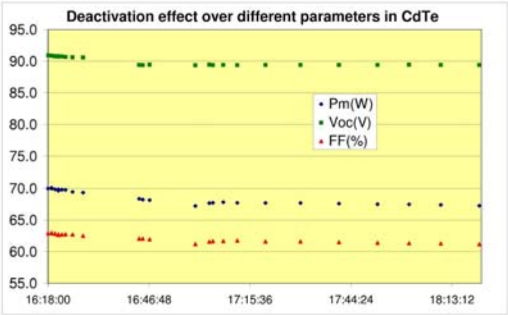

Figure 8.- As the CdTe PV module is not receiving sunlight different parameters suffer the deactivation effect.

4. CONCLUSIONS.

A reliable method for measuring electrical characteristics of thin film PV modules at STC is desirable. This method should be easy to accomplish so that manufacturers could use it. To accomplish this, measurements indoors in a solar simulator is always suggested observing the preconditioning for each thin film technology. This preconditioning always implies a period of time receiving sunlight for several days (or several months in the case of a-Si) in order to achieve the stabilized power state. Some technologies such as CIS and CdTe also need to receive sunlight for several hours prior to obtain a reliable measurement that take into account the activation effect in these technologies. In the case of CdTe the measurements should be obtained as soon as possible (less than five minutes) after the sunlight activation.

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